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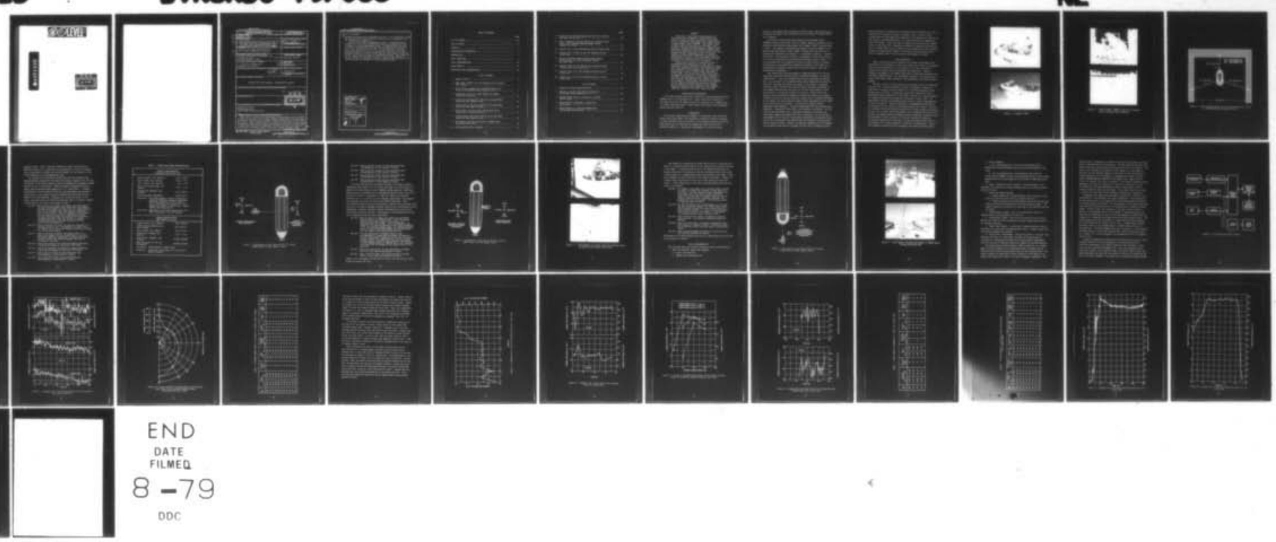

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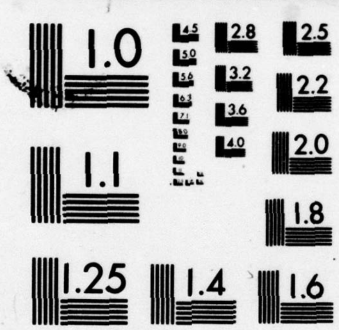

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The David W. Taylor Naval Ship Research and Development Center (DTNSRDC) conducted full-scale trials to gather tug/ship interaction forces developed by an advanced, right-angle drive tugboat (TINA) in maneuvering a tanker (YUKON). The overall intent of these trials is to modify the "tug effect" subroutine at the Maritime Administration Computer Aided Operations Research Facility (CAORF) at Kings Point, New York by developing, from the full-scale trial data presented herein, percentage factors to discount nominal tug thrust under

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appropriate situations to approximate the effect of flow conditions around the tug propellers created by motion of the tug, or the position of the tug relative to the tanker.

Bollard pull trials were conducted at Pier 1, Philadelphia Naval Shipyard on 10 July 1978 to establish a baseline performance with which to compare the tanker maneuvering trials. The maneuvering trials were conducted in the Chesapeake Bay area, near the measured mile course off Kent Island, Maryland on 25 July 1978. The bollard pull trials data present the maximum line force for a stationary condition of the TINA. The maneuvering trials results present data on thrust reduction when the tugboat is pulling at an angle to a moving ship, lateral thrust reduction for the tugboat resulting from the ship's forward motion, and astern thrust reduction of the tugboat caused by cavitation and vibration of the tugboat's propellers induced by the ship's speed and wake.

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ABSTRACT

The David W. Taylor Naval Ship Research and Development Center (DTNSRDC) conducted full-scale trials to gather tug/ship interaction forces developed by an advanced, right-angle drive tugboat (TINA) in maneuvering a tanker (YUKON). The overall intent of these trials is to modify the "tug effect" subroutine at the Maritime Administration Computer Aided Operations Research Facility (CAORF) at Kings Point, New York by developing, from the full-scale trial data presented herein, percentage factors to discount nominal tug thrust under appropriate situations to approximate the effect of flow conditions around the tug propellers created by motion of the tug, or the position of the tug relative to the tanker.

Bollard pull trials were conducted at Pier 1, Philadelphia Naval Shipyard on 10 July 1978 to establish a baseline performance with which to compare the tanker maneuvering trials. The maneuvering trials were conducted in the Chesapeake Bay area, near the measured mile course off Kent Island, Maryland on 25 July 1978. The bollard pull trials data present the maximum line force for a stationary condition of the TINA. The maneuvering trials results present data on thrust reduction when the tugboat is pulling at an angle to a moving ship, lateral thrust reduction for the tugboat resulting from the ship's forward motion, and astern thrust reduction of the tugboat caused by cavitation and vibration of the tugboat's propellers induced by the ship's speed and wake.

ADMINISTRATIVE INFORMATION

The trials reported herein were authorized by Maritime Administration (MARAD) letter of 30 September 1977. These trials were conducted in accordance with the test agenda received as enclosure (1) to MARAD letter of 5 April 1978 under David W. Taylor Naval Ship Research and Development Center Work Unit 1536-178.

INTRODUCTION

The Maritime Administration (MARAD), in conjunction with the United States Coast Guard (USCG), has undertaken a program to improve the safety of tanker operations and to contribute to the existing data base which the Coast Guard uses in fulfilling its obligations under the Ports and Waterways Safety Act. Through the encouragement of the use of more

effective tug systems and/or methods for their control, the probability of oil spills and repair costs associated with the berthing of larger tankers can be reduced.

The David W. Taylor Naval Ship Research and Development Center (DTNSRDC) conducted full-scale trials to gather tug/ship interaction forces developed by an advanced "right-angle" drive tugboat (TINA) in maneuvering a tanker. The Computer Aided Operations Research Facility (CAORF) at the National Maritime Research Center (NMRC) in Kings Point, New York has a program which simulates the docking of a conventional tanker at a representative pier. This program is about to be expanded to include the effect of up to six tugs operating at pre-determined positions around a tanker. It is also hoped that this program can be used to permit pilots to evaluate alternatives in tug selection and handling techniques in the light of an approximation of measured capabilities of specific types of tugs under representative conditions.

The problem with existing methods of comparing tugboats is that the comparison is generally based on either installed horsepower or measured "bollard pull". Since the customary bollard pull represents the maximum pull a tug can exert in the ahead direction while being held stationary in the water, this does not reflect the effect of the tugboat's propeller efficiency which is affected by the rate and/or direction of movement of the tugboat resulting from the motion of the ship being handled, and/or the position of the tugboat relative to the ship. These factors vary greatly between conventional tugboats in which full thrust can be exerted primarily in the fore and aft direction, subject only to lateral deflection by the rudder, and certain advanced tugs in which approximately full thrust can be exerted in any direction. In this latter category are two significant sub-categories: rotatable right-angle drive and vertical axis propulsion. Operational tests lead to three general conclusions: (1) the vertical axis propulsion unit is the most responsive, featuring quick, directional change with blades which can be feathered; (2) the rotatable right-angle drive is slower in directional response but has greater thrust; and (3) the conventional type tugboat has less capability for directional control than the others. However, the inherent simplicity of the straight-line propeller shaft makes it possible for this type of tugboat to exert

more ahead thrust in proportion to installed power and capital cost than is possible with the other two types of tugboats cited. Thrust of both conventional and right-angle drive tugboats can be augmented by addition of Kort nozzles, and maneuverability of all three types can be augmented by twin-screw design. Since each type of tugboat has both merits and limitations, a need exists for a quantitative method of comparing tug effectiveness in a manner which can be translated into operating costs and therefore be used in evaluating the capital and operating costs among alternative types of tugboats used for the assistance and docking of tankers.

TRIAL CONDITIONS

TINA, a twin-screw docking tugboat with rotatable right-angle drive propulsion units operating in a Kort type nozzle, was chosen for exploratory tests to gain information on the feasibility of the test operations, simulation techniques, and the associated instrumentation. Figure 1 presents photographs of the tugboat TINA which is owned and operated by the Wilmington Launch Service, Inc., Wilmington, Delaware. The representative tanker, USNS YUKON, shown in Figure 2, was provided by the Military Sealift Command.

The first series of tests conducted were bollard pull trials employing only the TINA. This was necessary in order to establish a baseline of performance consistent with the condition of the TINA's propulsion units during the trial period. Bollard pull trials were conducted at Pier 1, Philadelphia Naval Shipyard on 10 July 1978. Figure 3 is a sketch showing the tugboat mooring set-up during the bollard pull trials. Pier 1 is approximately 180 feet (54.9 meters) wide and has a depth of approximately 31 feet (9.4 meters). Several conditions or recommendations exist which are necessary for the conduct of successful bollard pull trials. They are: (1) the site of the trial should be such that the least possible circulation is set up in the water around the tugboat; (2) to minimize circulation still further, the engines should be warmed up before conducting the actual trial; (3) the depth of water in which the trials are carried out should be recorded and should not be less than 1.5 times the maximum after draft of the tugboat; (4) if trials cannot be carried out in slack water, a mean of pulls measured alternately with and against the current should be taken;

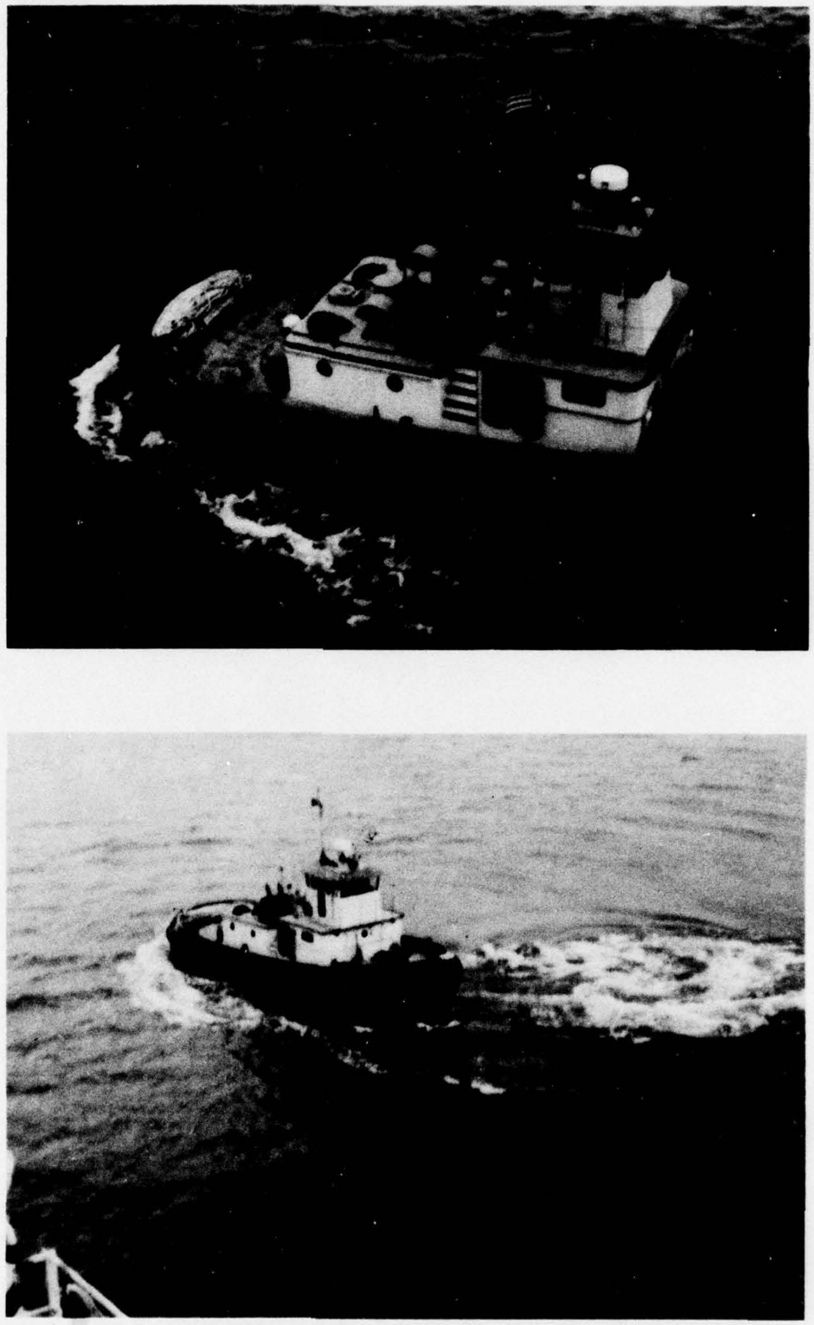

Figure 1 - Tugboat "TINA"

Figure 2 - USNS Tanker "YUKON" with the Pressure Plate Attached Near Midships

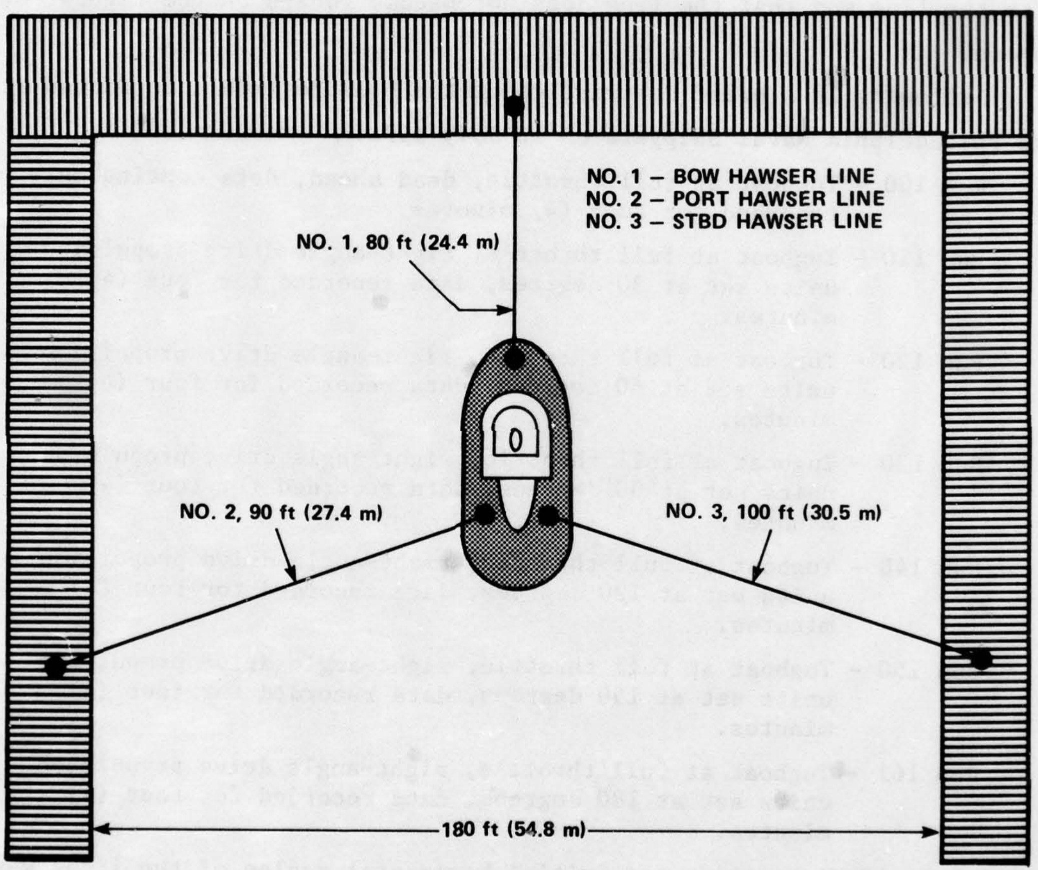

Figure 3 - Sketch Showing Tugboat Set Up During Bollard Pull Trials at Philadelphia Naval Shipyard, Pier 1

(5) the hawser length should be such as to allow the distance between the sternpost and the dock wall to be a minimum of 1.5 times the length of the tugboat (if practicable); (6) the inclination of the hawser should be as near horizontal as possible; and (7) arrangements should be made to ensure that the instrument used to measure the load in the line (in this case a 50,000 pound (222,400 newton) load cell) can swing freely to align itself with the line and that the line does not become fouled on the tugboat or ashore.

Following is a brief description of the bollard trials conducted at the Philadelphia Naval Shipyard on 10 July 1978.

Run 100 - Tugboat at full throttle, dead ahead, data continuously recorded for four (4) minutes.

Run 110 - Tugboat at full throttle, right-angle drive propulsion units set at 30 degrees, data recorded for four (4) minutes.

Run 120 - Tugboat at full throttle, right-angle drive propulsion units set at 60 degrees, data recorded for four (4) minutes.

Run 130 - Tugboat at full throttle, right-angle drive propulsion units set at 90 degrees, data recorded for four (4) minutes.

Run 140 - Tugboat at full throttle, right-angle drive propulsion units set at 120 degrees, data recorded for four (4) minutes.

Run 150 - Tugboat at full throttle, right-angle drive propulsion units set at 150 degrees, data recorded for four (4) minutes.

Run 161 - Tugboat at full throttle, right-angle drive propulsion units set at 180 degrees, data recorded for four (4) minutes.

Initial residual tensions and initial horizontal angles of the lines were recorded prior to the start of a run so that corrections to recorded values could be made during the run.

The remaining series of trials, Run Groups 300, 400, and 500 were conducted in the Chesapeake Bay area near the measured mile course off Kent Island, Maryland on 25 July 1978. Figure 4 presents a chart of the Chesapeake Bay area in which the tanker and tugboat trials were conducted. In order to determine ship speed, the tanker was continuously tracked by two shore stations; one located at Thomas Point Shoal and the other at

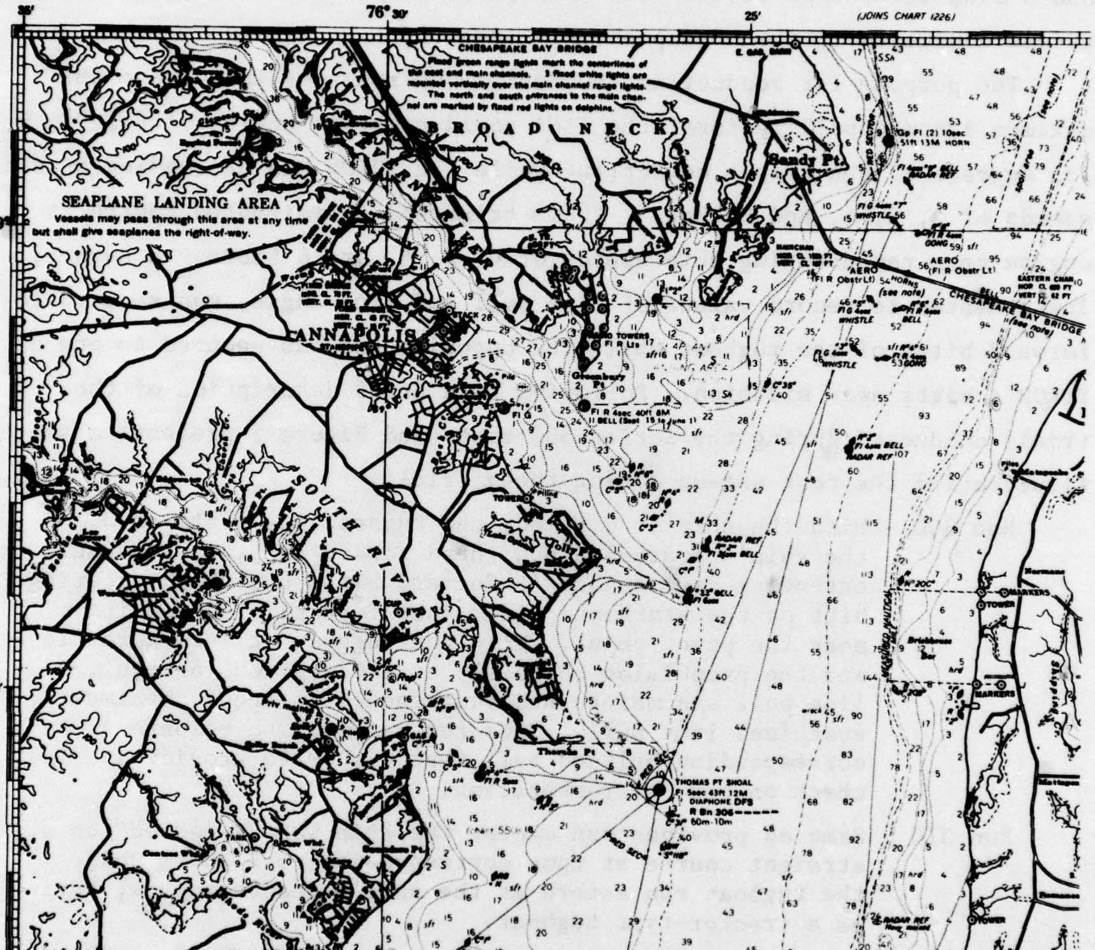

Figure 4 - Chesapeake Bay Area in which Tanker and Tugboat Trials were Conducted

Greenbury Point. Table 1 presents tugboat and tanker characteristics. YUKON was ballasted to a mean draft of approximately 20 feet (6.1 meters) and a displacement of 16,000 tons (16,256 tonnes) for the duration of the trials conducted in the Chesapeake Bay area.

The purpose for conducting the Series 300 runs was to measure the maximum dynamic pulling force the TINA could exert at angles of 45, 90, and 135 degrees to the ship's centerline while the YUKON was proceeding at ahead speeds of 0, 2, 4, and 6 knots. YUKON traversed a designated course at engine rpms representing ship speeds of 0, 2, 4, and 6 knots. A hawser, instrumented to record values of line pull and line angle, was secured to forward bitts of the tugboat while the opposite end was secured to one of YUKON's bitts near midships. Following is a brief description of the trials conducted during the Series 300 tests and Figure 5 presents a sketch illustrating the test set-up during these trials.

Run 300 - With the ship at 0 speed, the tugboat was positioned at the ship's starboard bow, head toward ship, with hawser extending from tugboat's forward bitt to a ship's mooring bitt on the starboard side, just forward of amidships near the pivot point. With the tugboat at full throttle and the propulsion units set at 180 degrees (astern), line pull was maintained long enough to record maximum sustained line pull. This run was used to compare corresponding bollard pull test values to provide a check on the instrumentation.

Run 310 - Same as previous run except the ship was "steadied" on a straight course at rpms corresponding to 2 knots while the tugboat ran astern at the ship's starboard bow, acting as a tractor-type tugboat.

Run 315 - Same as previous run except the tugboat moved to a position 45 degrees off the starboard bow of the ship and assumed whatever combination of tugboat heading and propeller angles that produced maximum line pull at 45 degrees to the ship.

Run 320 - Same as the previous run except the tugboat maintained a position 90 degrees on the beam of the tanker.

Run 325 - Same as the previous run except the tugboat maintained a position 135 degrees on the beam of the tanker.

Run 330 - Same as Run 315 except the ship maintained rpms corresponding to a ship speed of 4 knots.

Run 335 - Same as Run 320 except the ship maintained rpms corresponding to a ship speed of 4 knots.

TABLE 1 - TUGBOAT AND TANKER CHARACTERISTICS

TUGBOAT CHARACTERISTICS Wilmington Launch Tug, TINA	
Length Overall, feet (meters)	65.0 (19.8)
Beam, Molded, feet (meters)	26.0 (7.9)
Draft, Molded, feet (meters)	9.0 (2.7)
Draft to Bottom of Skeg, feet (meters)	10.5 (3.2)
Displacement (Design), tons (tonnes)	127.5 (129.5)
Brake Horsepower (kilowatts)	1,000 (745.7)
Propulsion: Two diesel engines coupled to Murray and Tregurtha 360-degree steerable propulsion units with propellers in Kort nozzles. The two propellers are mounted aft. The tugboat is designed to operate as a tractor tugboat when going astern.	
Propellers: Right-hand, four-bladed, Kaplan type; 5.33 feet (1.62 meters) in a Kort nozzle.	
TANKER CHARACTERISTICS USNS YUKON (T-5 Class)	
Length Overall, feet (meters)	620.0 (189.0)
Length between Perpendiculars, feet (meters)	590.0 (179.8)
Beam, Molded, feet (meters)	83.5 (25.4)
Design Draft, Molded, feet (meters)	31.8 (9.7)
Displacement (Design), tons (tonnes)	25,000 (25,400)
Shaft Horsepower at 101 rpm (kilowatts)	18,600 (13,870)
Propulsion: Steam turbines, single screw.	
Propeller: Right-hand, five-bladed; 20.5 feet (6.25 meters) diameter.	

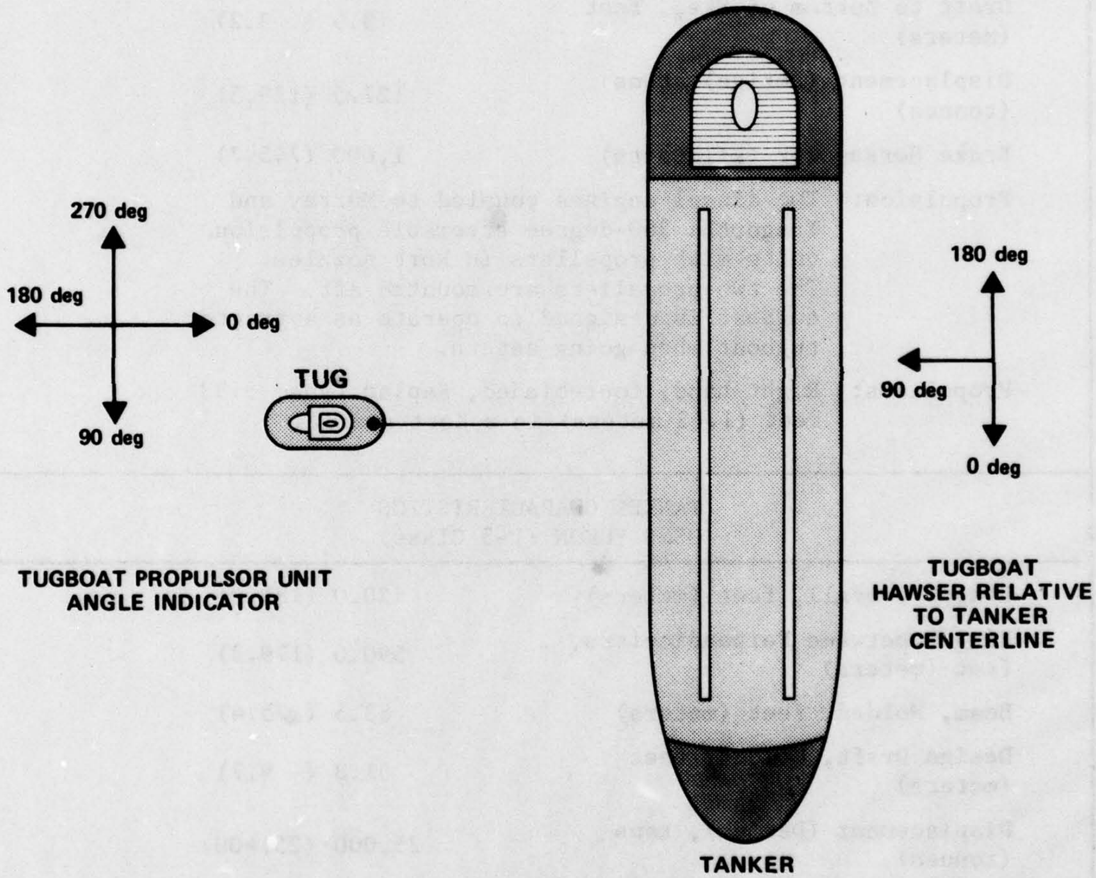

Figure 5 - Illustration of Run Series 300 Set Up During YUKON Tanker and TINA Tugboat Trials

Run 340 - Same as Run 325 except the ship maintained rpms corresponding to a ship speed of 4 knots.

Run 355 - Same as Run 315 except the ship maintained rpms corresponding to a ship speed of 6 knots.

Run 360 - Same as Run 320 except the ship maintained rpms corresponding to a ship speed of 6 knots.

Run 365 - Same as Run 325 except the ship maintained rpms corresponding to a ship speed of 6 knots.

The Series 400 runs were conducted in order to determine possible limitations ship speeds of 0 to 6 knots place upon the effectiveness of a tugboat while operating at a ship's midbody during emergency conditions. Thrust data were determined by an instrumented loading frame, 8 feet (2.4 meters) by 10 feet (3.0 meters) by 3 feet (0.9 meter) and weighing approximately 2 to 3 tons (2.0 to 3.0 tonnes), positioned on the tanker's port midships just above the 20-foot (6.1-meter) waterline. This instrumented loading frame was positioned in a manner which prevented either vertical or horizontal movement in order that the test results would not be jeopardized. Figure 6 presents a sketch illustrating the trial set-up used during the Series 400 runs. Following is a brief description of the tests conducted during the Series 400 trials.

Run 400 - With the ship at 0 speed, the tugboat was positioned head-on against the loading frame. While the tugboat throttle was advanced from 0 to full power, the instrumentation was checked. Then the heading of the tugboat to the ship was shifted to check the performance of the instrumented loading frame. The maximum sustained thrust at full throttle was recorded for the period of time the tugboat could hold a given position.

Run 410 - The ship maintained a straight course at rpms corresponding to 2 knots and the tugboat ran parallel with the instrumented loading frame, and upon the execute command, contact was established with the instrumented loading frame at a position which permitted the tugboat to exert maximum thrust by combined use of the propulsion units angle and the heading of the tugboat while at full throttle.

Run 420 - Same as Run 410 except the ship maintained a straight source at ship rpms corresponding to 4 knots.

Run 430 - Same as Run 410 except the ship maintained a straight course at ship rpms corresponding to 6 knots.

Figure 7 is a photograph showing TINA in contact with the pressure plate during the Series 400 runs.

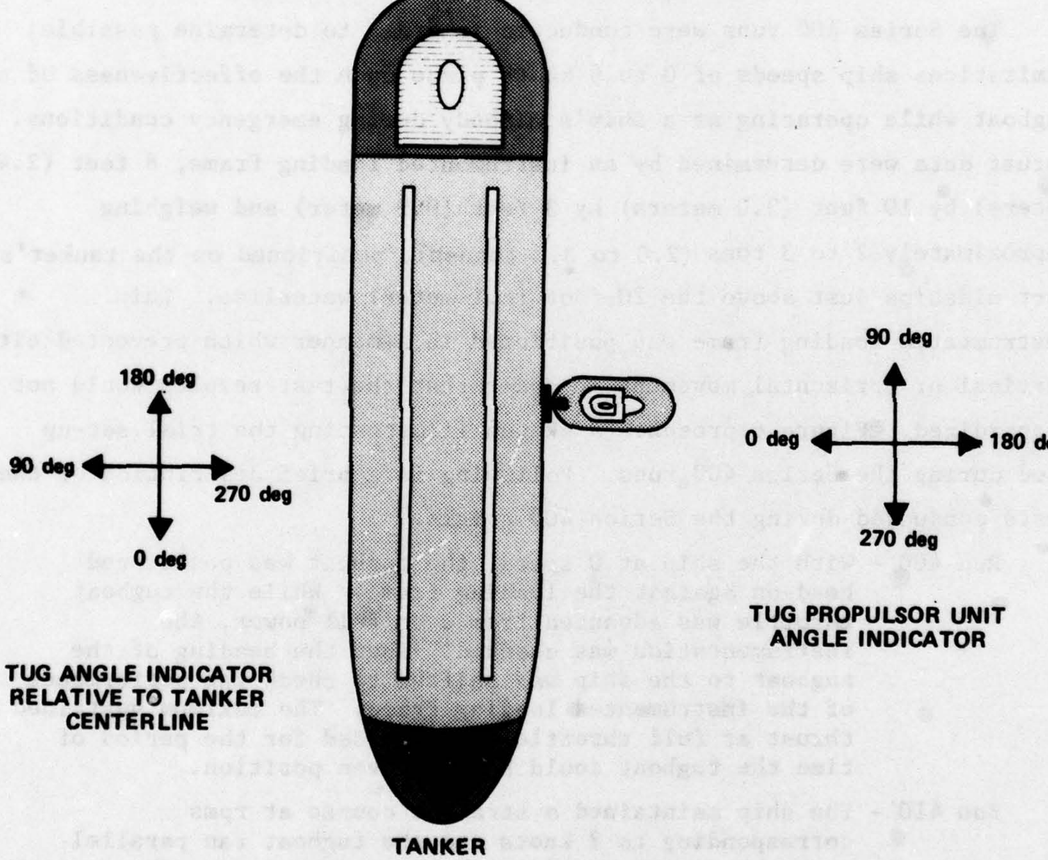

Figure 6 - Illustration of Run Series 400 Set Up During YUKON Tanker and TINA Tugboat Trials

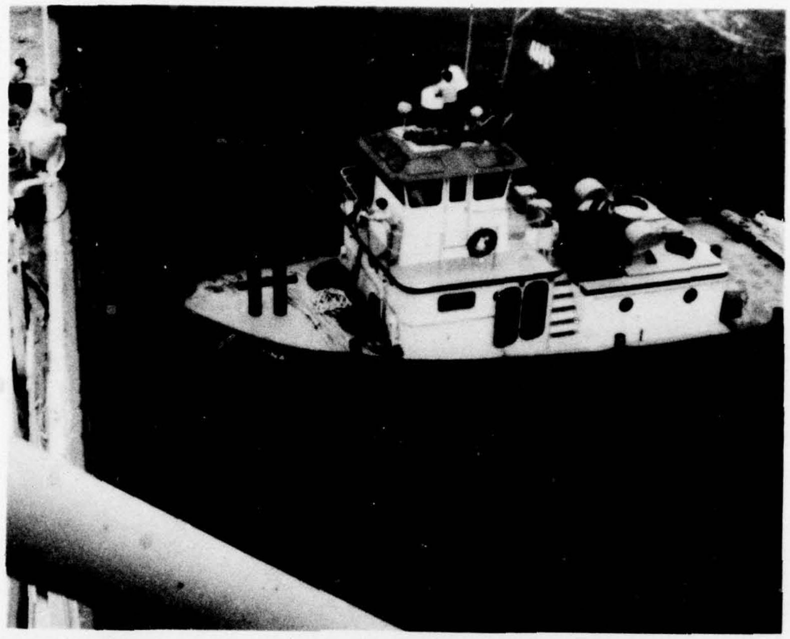

Figure 7 - TINA Tugboat in Contact with the Pressure Plate During the Run Series 400 Trials

The purpose for conducting the Series 500 tests was to establish the effect of the ship's forward motion on the tugboat when pulling from astern of the tanker. A limiting speed at which the tugboat's propellers can operate effectively in slowing the ship was determined during these tests. A towing hawser of a predetermined length was secured to the tanker's stern bitts through the stern chock and to the tugboat's bow bitts. Figure 8 is a sketch which illustrates the test set-up used during the Series 500 trials. A brief description of the tests conducted during the Series 500 trials is as follows.

Run 500 - The tugboat, with hawser from the ship's stern, trailed aft until the tanker had attained a steady speed of 6 or 8 knots. The ship maintained rpms representing the final speed while the tugboat pulled with astern thrust at full throttle, or whatever throttle setting could be achieved without excessive vibration, and maximum line pull was recorded. The ship was tracked to determine speed reduction.

Run 510 - The ship maintained rpms corresponding to 4 or 6 knots and upon an execute command, the engines were stopped and the tugboat exerted full power astern until the ship either was brought to a stop or it was determined that the ship could not be brought to a stop within a reasonable distance and/or period of time.

Run 520 - Same as previous run except an attempt at a greater speed was made. The speed was determined during the testing.

Run 530 - Same as Run 520 except the tugboat's propulsion units were directed 15 degrees outboard to determine whether or not this was a more effective means of pulling from astern.

Run 540 - Same as Run 530 except the tugboat's propulsion units were directed outboard 30 degrees.

Photographs of the TINA pulling from astern of YUKON during the Series 500 runs are shown in Figure 9.

TRIAL INSTRUMENTATION

The following data were recorded during the trials reported herein:

1. Shaft rpm (tanker); Engine rpm (tugboat)
   a. Tanker rpm (manually)
   b. Tugboat rpm (electronically)

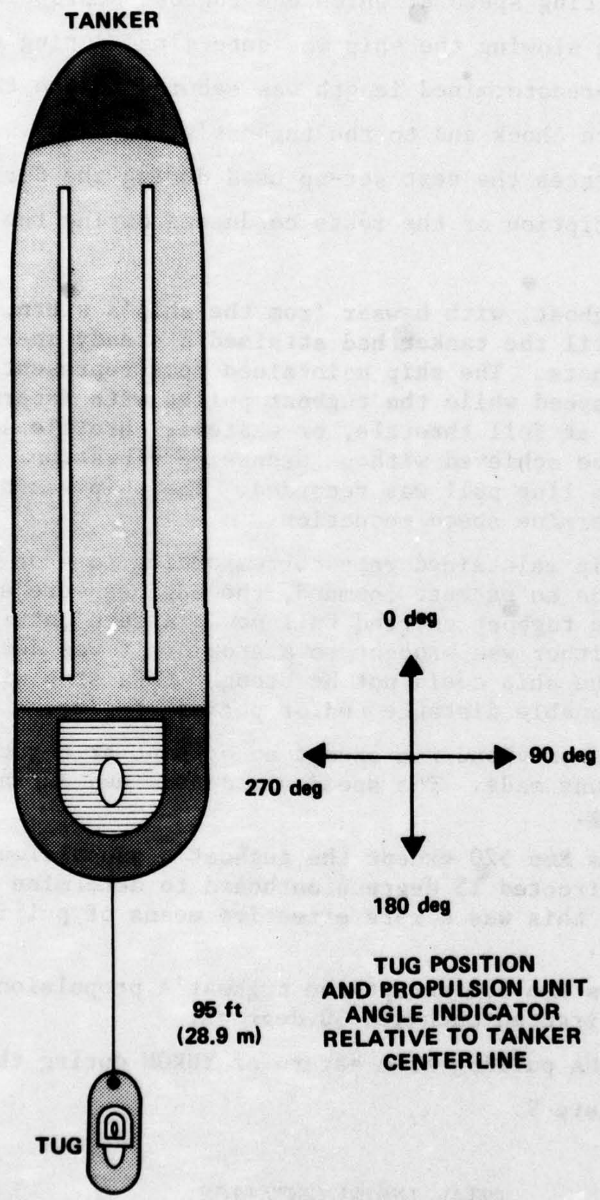

Figure 8 - Illustration of Run Series 500 Set Up During YUKON Tanker and TINA Tugboat Trials

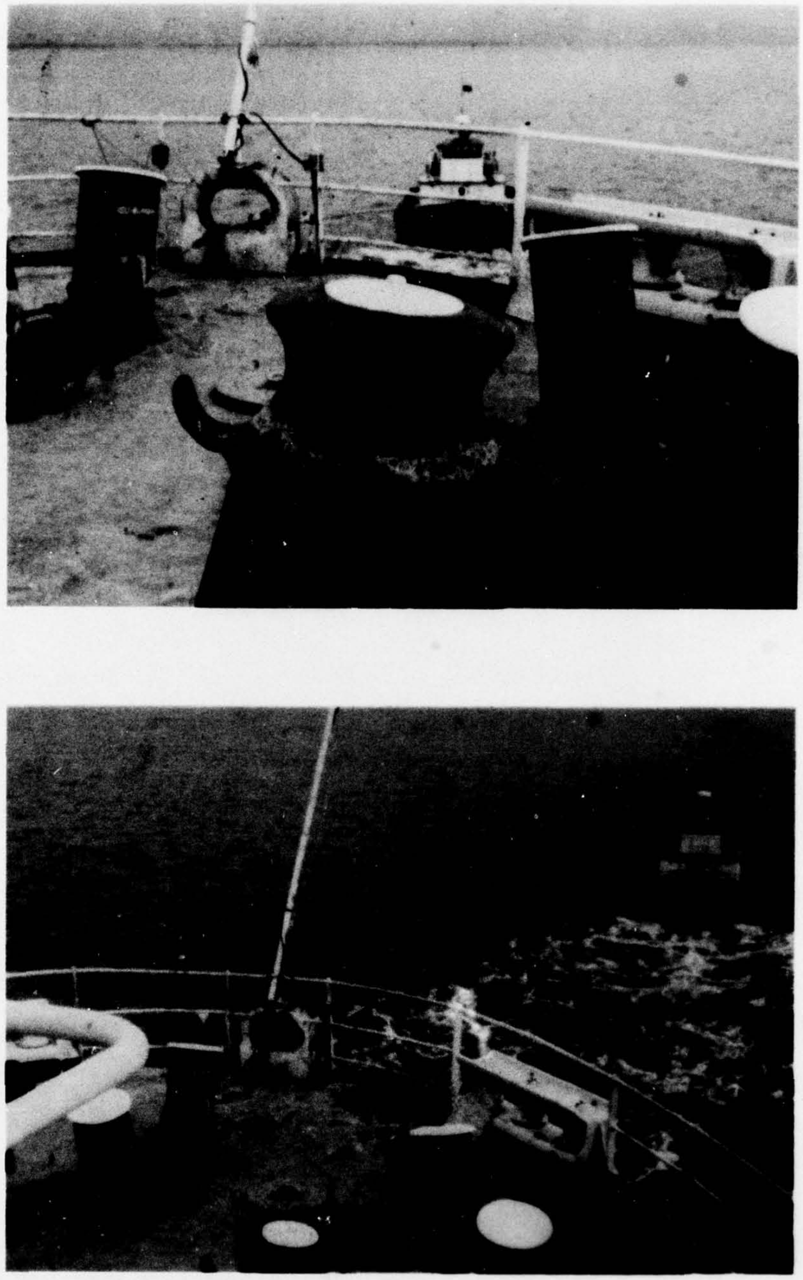

Figure 9 - TINA Tugboat Pulling from Astern of YUKON Tanker During Run Series 500

2. Thrust (tugboat)

a. For the pulling tests, a line was instrumented with a 50,000 pound (222,400 newtons) load cell for the recording of line force.

b. For the pushing tests, an instrumented load frame was constructed by DTNSRDC and this frame contained several load carrying members which were strain gaged for the purpose of measuring thrust data.

3. Angle of Propulsion Units (tugboat) - The measurement of the propulsion unit angles was recorded electronically on a continuous basis during the trials.

4. Tanker and Tugboat Heading

a. Tanker heading was recorded manually every 15 minutes along with sea conditions, wind velocity, and wind direction.

b. Tugboat heading was recorded manually during the bollard pull trials and during the maneuvering trials involving the tanker. The tugboat heading was positioned, as required, by the specific test and run number.

5. Towing Hawser(s) Angle - This was accomplished by means of a template which was read manually for each run.

6. Towing Hawser Length - This was done during the test set-up by marking the hawser and later measuring the hawser length between marks in the unloaded condition.

7. Tanker Speed (knots) - An electronic ranging system was used to determine ship speed during the maneuvering trials. A digital signal from the ranging equipment was recorded.

8. Tanker Draft, Displacement - During the transit to the trial area, YUKON was ballasted to a mean draft of 20 feet (6.10 meters) which corresponds to approximately 16,000 tons (16,256 tonnes) displacement. The draft was read by personnel aboard the tugboat and recorded manually.

The loading frame (pressure plate), shown in Figure 8, is a strain-gaged structure designed to be sandwiched between the tugboat and the tanker during the special maneuvering trials of the Series 400 runs. The frame is capable of measuring the thrust imparted to the tanker by the tugboat and resolving the thrust into three orthogonal components. The

loading frame is designed to be lashed to the hull of the tanker in an area which is perpendicular to the waterline. The load frame has internal void space filled with styrofoam which provided buoyancy for the structure. The frame is not designed to be impacted by the tugboat at a high speed of approach, but can withstand impacts on the order of those encountered in normal operations, and is designed to a maximum axial thrust of 60,000 pounds (266,880 newtons) impacted by the tugboat for a target area of 8 feet (2.4 meters) by 10 feet (3.0 meters). The frame has maximum overall dimensions of 8 feet (2.4 meters) by 11.25 feet (3.4 meters) by 3 feet (0.9 meter) and is rubber cushioned in order to avoid metal to metal contact between the frame and the tanker. This rubber cushion also helps to prevent the frame from lateral movement during the test operations.

Propulsion unit angles were measured by installing a continuous turn potentiometer to the propulsor unit angle transmitter. The potentiometer was then excited with a DC voltage source and an analog signal indicative of propulsor angle was obtained. The strain gages in the loading frame and load cells were also excited with a DC voltage source to obtain an analog signal. Metallic slugs were installed on the shafts from the diesel engines to the propulsor units of the tugboat for determining shaft rpm. Shaft rpm was determined by the use of an electromagnetic pickup which was connected to a frequency-to-voltage converter giving an analog signal. The analog signals were then interfaced to a 2240A Hewlett-Packard processor unit which digitized the signals and fed them to a 9825A Hewlett-Packard calculator which in turn recorded them on a 9885M flexible disk to be analyzed later. The analog signals were also interfaced to a Vidar digital recording printer in order that selected data could be monitored during a run. Figure 10 is a block diagram of the instrumentation for the tugboat-tanker trials.

Several instrumentation problems were encountered during these trials. Problems associated with the measurement of rpm included excessive vibrations experienced in the shafts causing the rpm connectors to work lose, and the rpm pickup was damaged due to the close placement of the pickup with respect to the metallic slugs. During the tanker trials, the speed measurement was inaccurate and failed to provide the information for which it had been intended. The reasons for the speed measurement problem

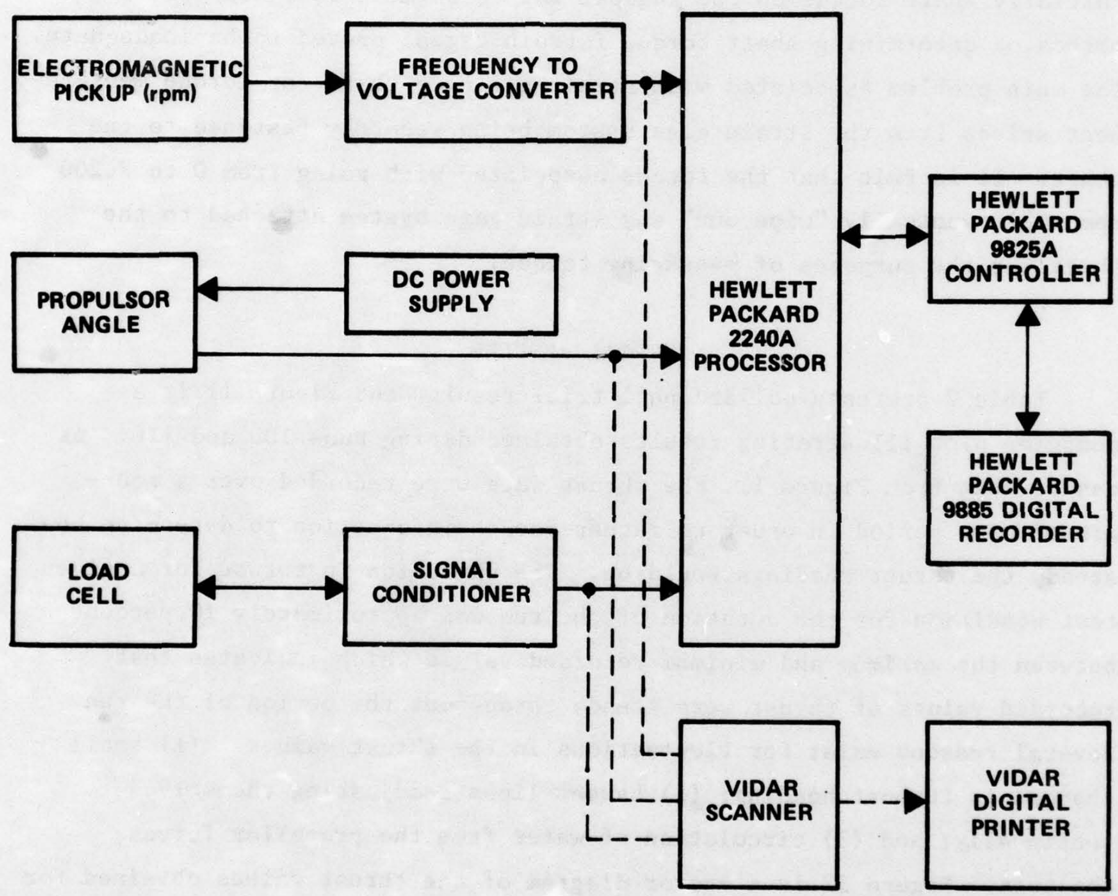

Figure 10 - Instrumentation Block Diagram

included: (1) the sample rate was too slow for the short run duration; and (2) due to the nature of the trials, and the necessity for the completion of the trials within a one-day time period, steady run approaches for accurate speed measurements prior to the start of a run were not made. Initially shaft torque on the tugboat was to be measured; however, the method of determining shaft torque (strain gages) proved to be inadequate. The main problem associated with strain gaging a shaft for torque measurement arises from the strain gage system being securely fastened to the shaft. It is felt that the forces associated with going from 0 to 2,200 rpm will eventually "wipe out" any strain gage system attached to the shaft for the purposes of measuring torque.

TRIAL RESULTS

Table 2 presents bollard pull trial results and Figure 11 is a computer plot illustrating results obtained during Runs 100 and 110. As can be seen from Figure 11, the thrust data were recorded over a four-minute time period in order to gather enough information to determine how steady the thrust readings would be. The variation in thrust for a given test condition for the duration of the run was approximately 10 percent between the maximum and minimum recorded values which indicates that recorded values of thrust were steady throughout the period of the run. Several reasons exist for fluctuations in the thrust values: (1) small changes in tugboat heading; (2) hawser lines readjusting themselves continually; and (3) circulation of water from the propeller forces the test. Figure 12 is a vector diagram of the thrust values obtained for each propeller heading change. The recorded values ahead and astern are the same for all practical purposes, and the minimum value recorded was for a heading of 30 degrees. Close examination of Table 2 will show a significant difference between the port and starboard engine rpms. This difference was observed throughout the trial period when the throttle settings were maintained at maximum. Whenever future trials of this nature are considered, rpm settings should be maintained at maximum and another equal rpm setting below maximum.

Talbe 3 presents trial results for maximum pull at an angle to a moving ship's course. Computer plots of Runs 300, 335, and 355, showing

TABLE 2 - RESULTS OF BOLLARD PULL TRIALS CONDUCTED AT PHILADELPHIA NAVAL SHIPYARD, PIER 1

Run No.	Pull (lb)	Pull (N)	Propulsion Unit Angle (deg)	Engine rpm STBD	Engine rpm PORT	Propeller rpm STBD	Propeller rpm PORT	Tug Heading (magnetic) (deg)
100	29,140	129,615	180	2329	1893	394	320	353
110	27,970	124,411	150	2336	1915	395	324	008
120	27,010	120,140	120	2284	1781	386	301	023
130	26,440	117,605	90	2258	1881	382	318	028
140	26,200	116,538	60	2337	1855	395	314	012
150	25,780	114,669	30	2322	1888	393	319	010
161	28,940	128,725	0	2264	1841	383	312	352

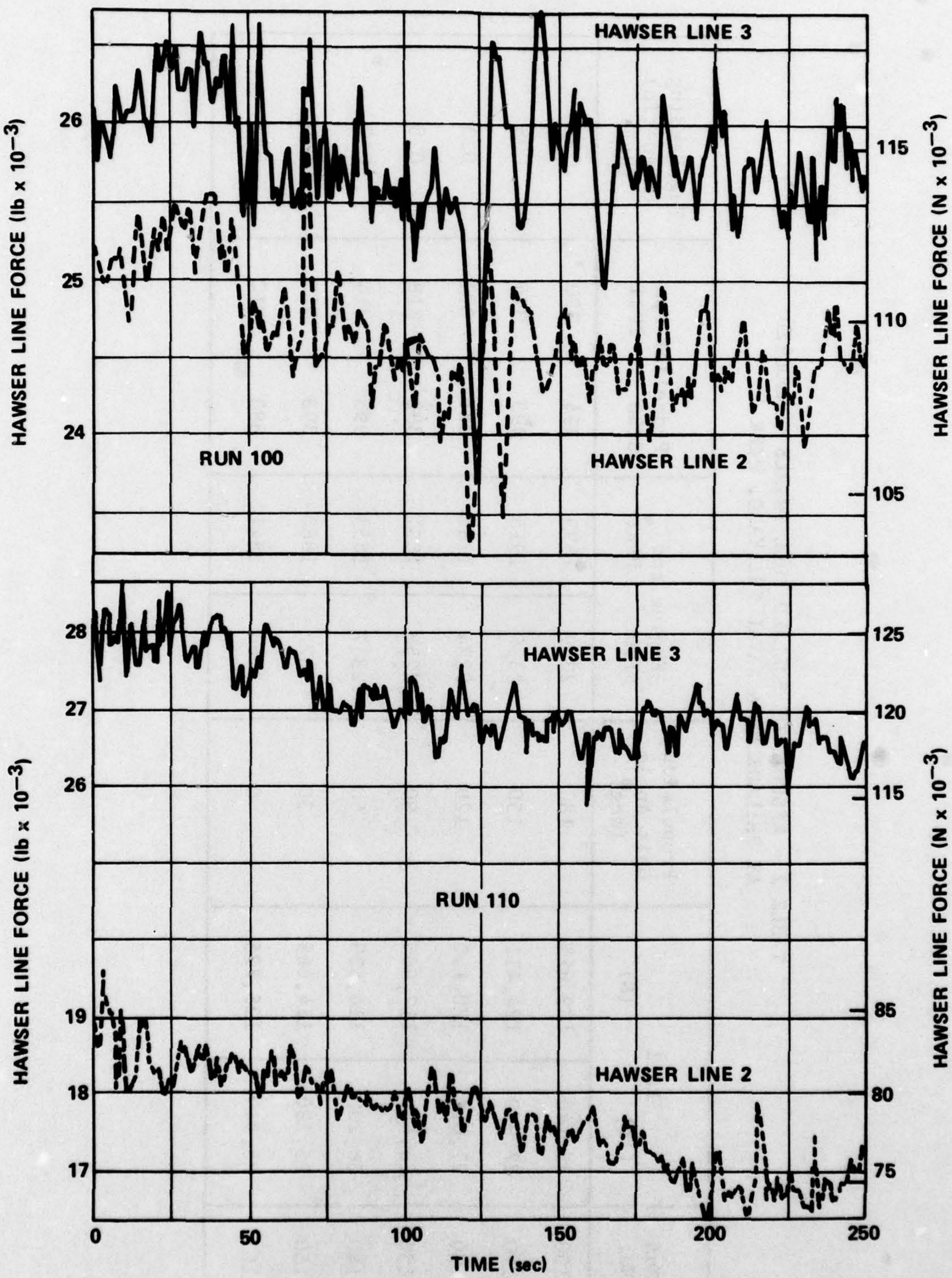

Figure 11 - Computer Plot Illustrating Bollard Pull Trial Results with Runs 100 and 110

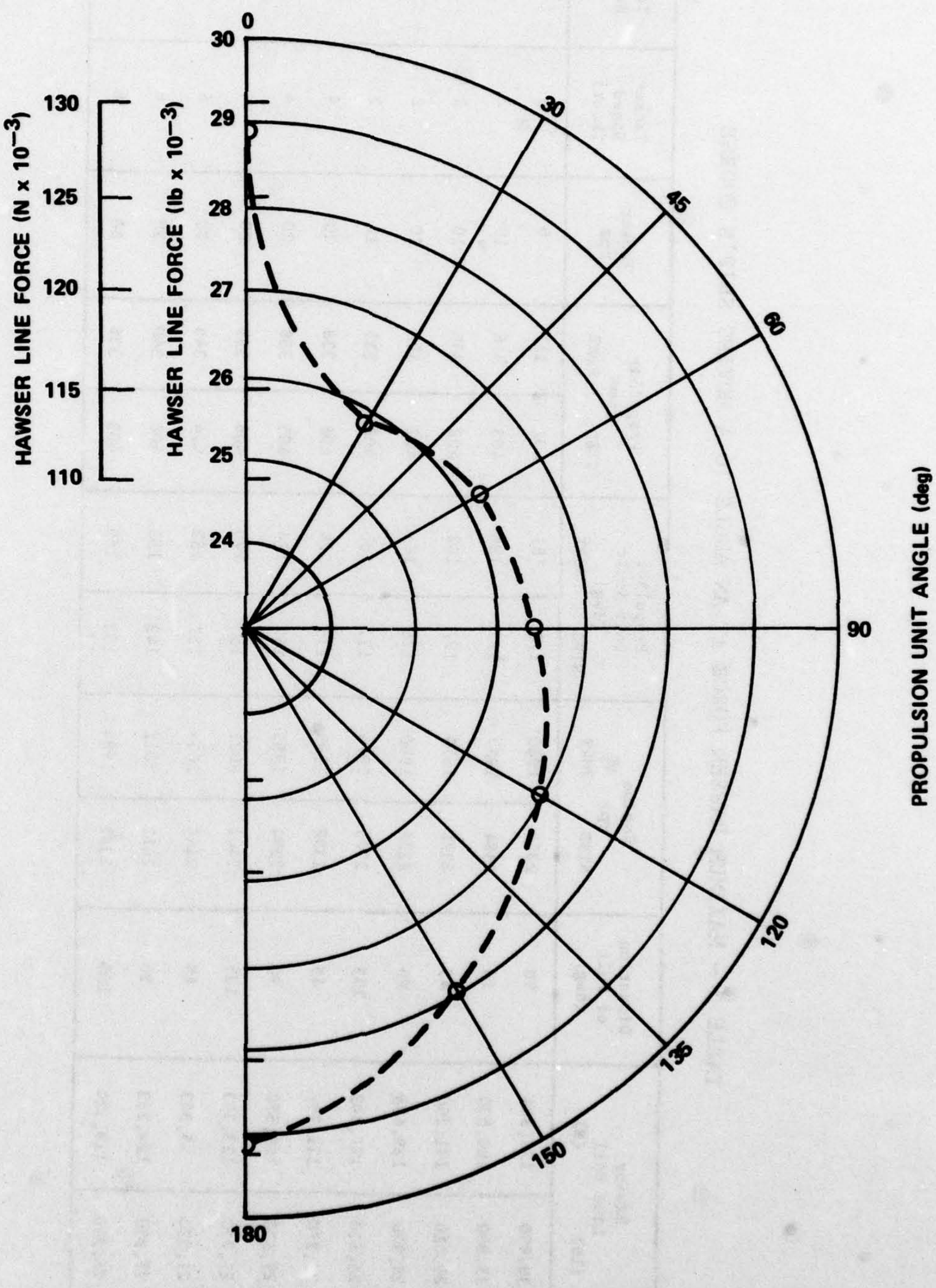

Figure 12 - Vector Diagram of Recorded Thrust for Rotatable Right-Angle Drive Propeller Heading Changes During Bollard Pull Trials

TABLE 3 - MAXIMUM HAWSER FORCE AT AN ANGLE TO A MOVING SHIP'S COURSE

Run No.	Hawser Line Pull (lb)	Hawser Line Pull (N)	Direction of Pull (deg)	Engine rpm STBD	Engine rpm PORT	Propulsor Unit Angle (deg) STBD	Propulsor Unit Angle (deg) PORT	Propeller rpm STBD	Propeller rpm PORT	Tanker rpm	Tanker Speed (knot)	Tanker Heading (deg)
300	30,990	137,844	90	2376	1980	175	181	402	335	0	0	197
310	23,950	106,530	10	2384	1987	177	186	403	336	10	2	199
315	29,510	131,260	45	2375	1979	177	182	402	335	10	2	199
320	28,920	128,636	90	2376	1980	176	181	402	335	10	2	199
325	28,620	127,302	135	2375	1979	177	180	402	335	10	2	199
330	27,270	121,297	45	2398	1998	175	178	406	338	20	4	167
335	29,130	129,570	90	2394	1995	167	176	405	338	20	4	167
340	27,730	123,343	135	2401	2001	153	170	406	339	20	4	167
355	21,570	95,943	45	2444	2037	157	152	414	345	30	6	163
360	27,930	124,233	90	2413	2011	143	153	408	340	30	6	163
365	26,840	119,384	135	2381	1984	152	166	403	336	30	6	163

line pull versus time, are presented in Figures 13 and 14. These series of tests were performed in order to show the reduction in thrust when pulling at an angle to a moving ship induced by the ship's forward motion. Figure 15 presents the curves of recorded thrust values versus tugboat heading angle for three ship speeds during Run Series 300. Upon close examination of Figure 15, it can be concluded that recorded line pull for a heading angle of 45 degrees significantly "falls off" with increasing ship speed while heading angles of 90 and 135 degrees are a gradual "fall off" in recorded line pull.

It had been expected that there would be a significant reduction in the ability of the tugboat to apply lateral thrust to the tanker with increasing ship speed. However, Figure 16, a computer plot of Run 400 showing recorded pressure plate data versus time, and Table 4 clearly show that TINA loses very little effectiveness in its ability to apply lateral thrust with ship speed. As can be seen from the table, there is only a 10 percent reduction in thrust between ship speeds of 0 and 6 knots. TINA was able to maintain a heading of 90 degrees (perpendicular to the ship) at all speeds except 6 knots.

Table 5 presents the effect of the ship's forward motion on the effectiveness of a trailing tugboat when pulling with astern thrust. Computer plots of Runs 500 and 510, showing recorded line pull versus time, are presented as Figures 17 and 18, respectively. The significance of the results presented in Table 5 can be realized by Runs 530 and 540. During Run 530, TINA's propellers were positioned 15 degrees outboard and for Run 540, the propellers were directed 30 degrees outboard. During the actual tests, observers aboard TINA experienced excessive vibration during Runs 530 and 540 and, therefore, these runs were very short. Maximum throttle settings were never achieved during any of the Series 500 runs. Also, directing the propellers outboard 15 and 30 degrees when pulling astern reduced line pull.

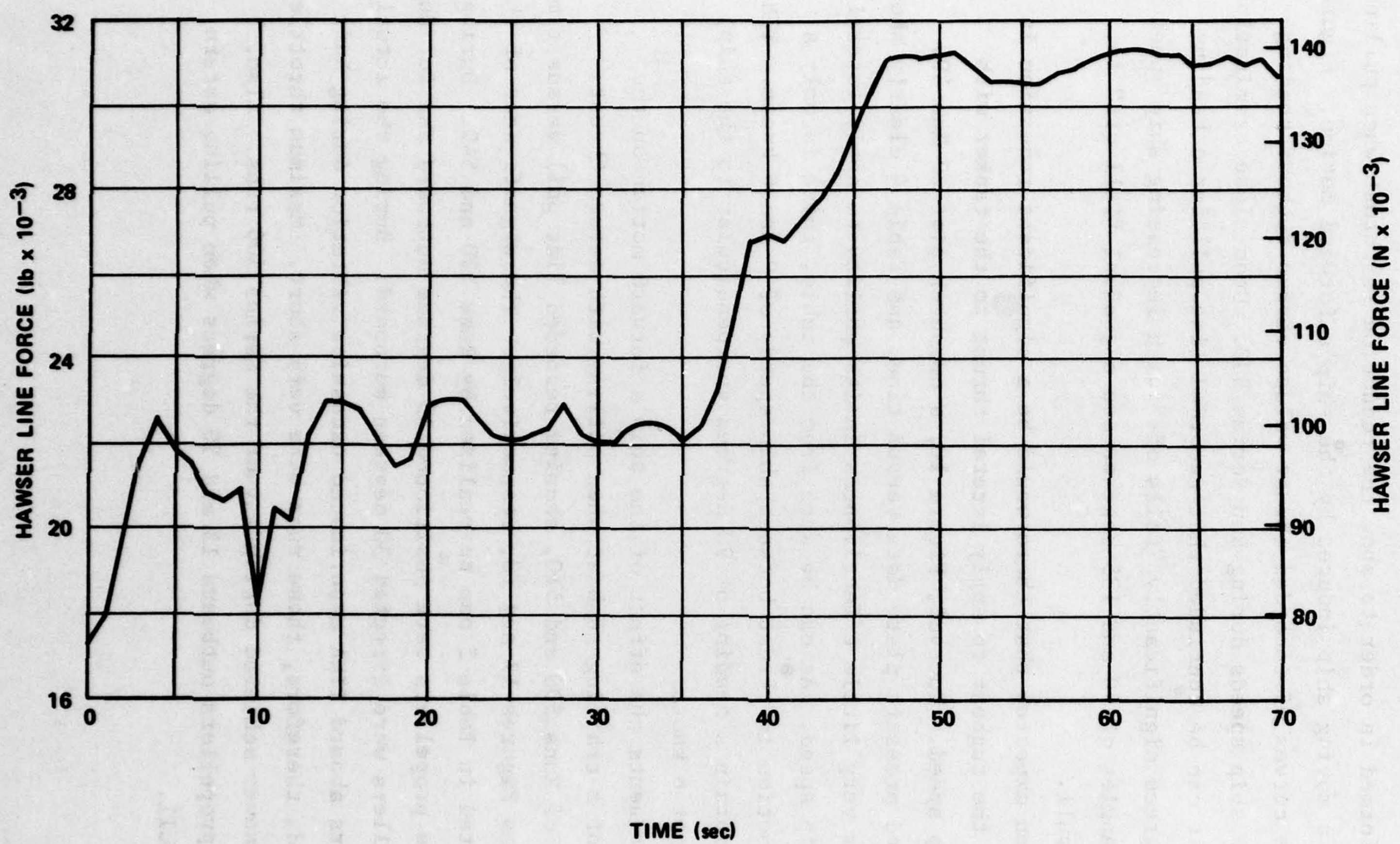

Figure 13 - Computer Plot of Run 300 Showing Line Pull versus Time

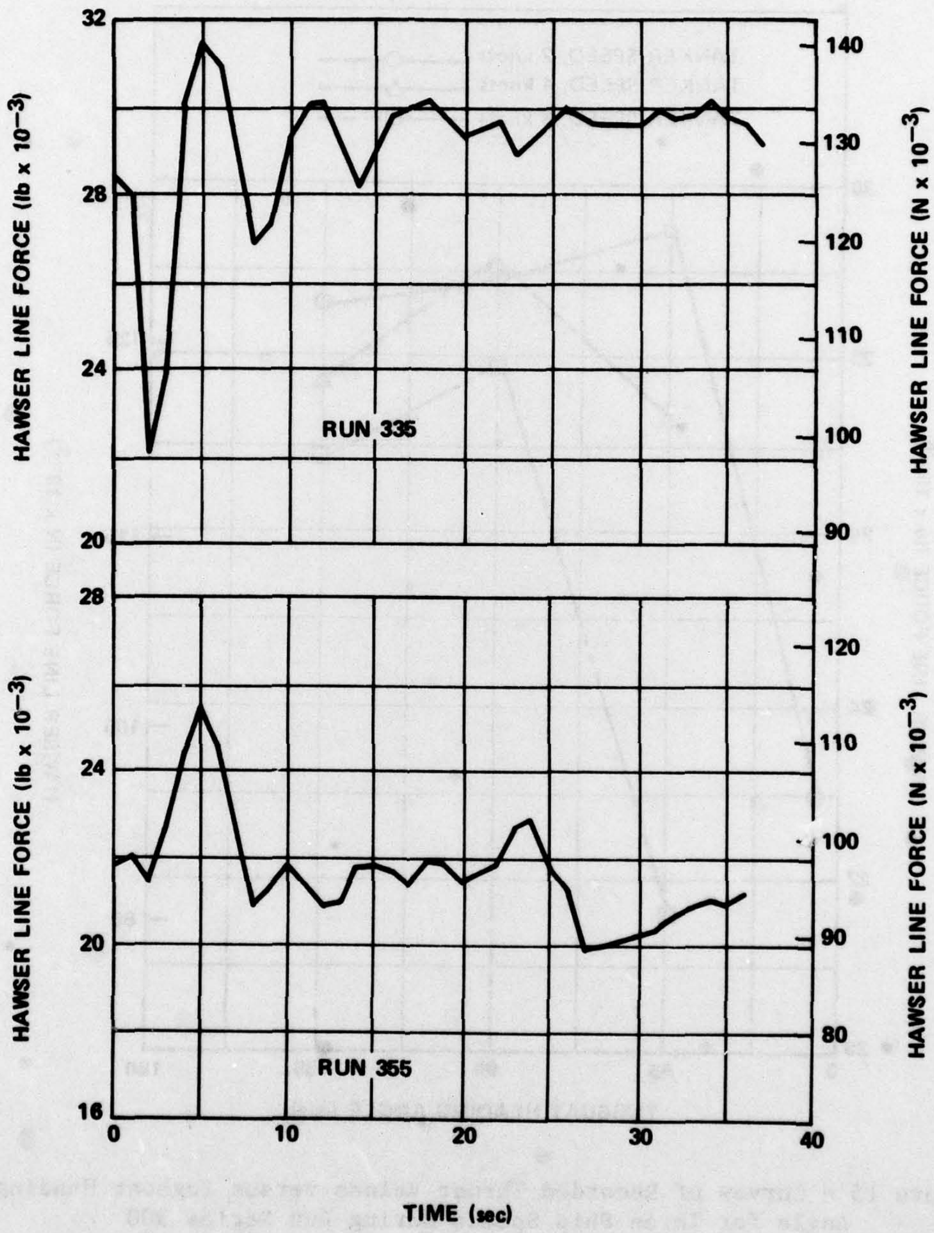

Figure 14 - Computer Plot of Runs 335 and 355 Showing Line Pull versus Time

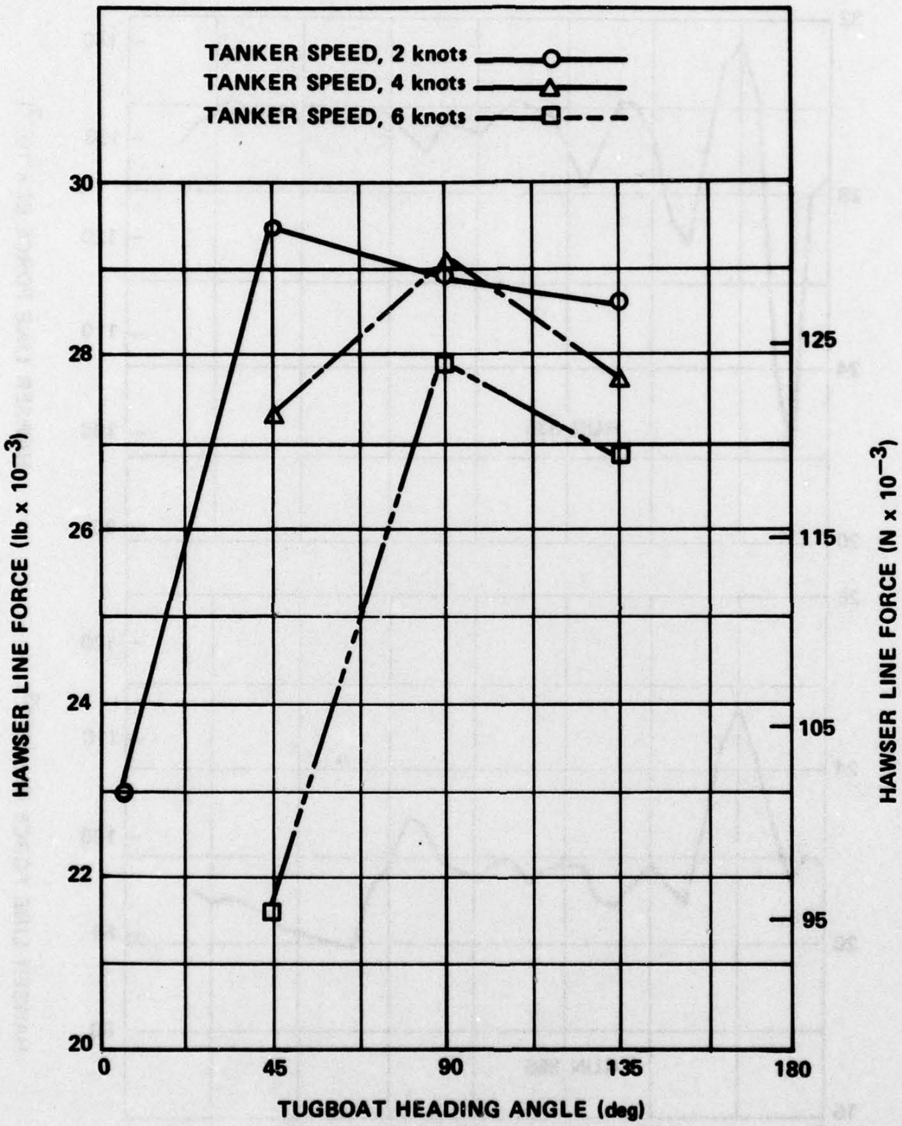

Figure 15 - Curves of Recorded Thrust Values versus Tugboat Heading Angle for Three Ship Speeds During Run Series 300

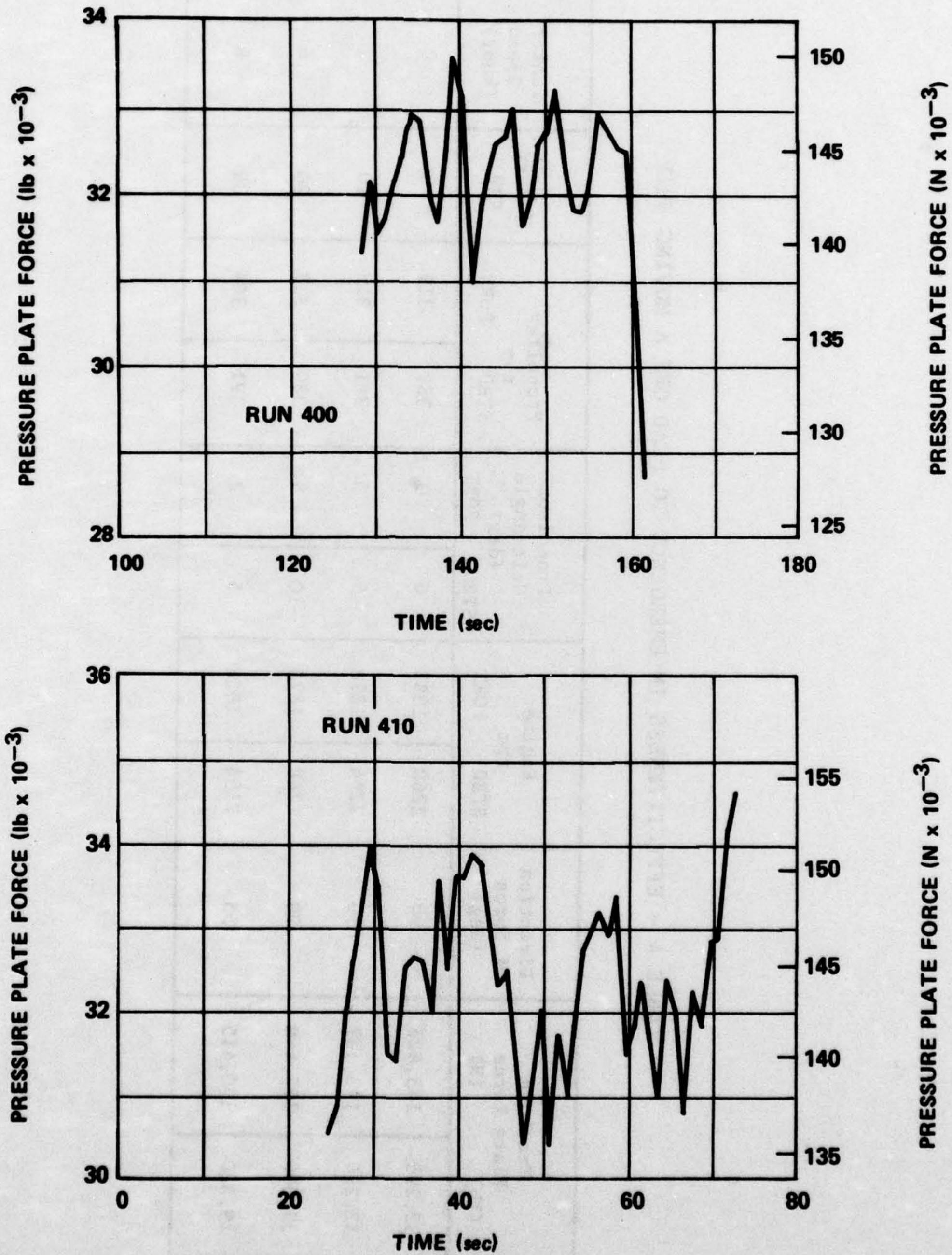

Figure 16 - Computer Plots of Runs 400 and 410 Showing Recorded Pressure Plate Data versus Time

TABLE 4 - EFFECTIVENESS IN EMERGENCY TO HEAD OFF A MOVING SHIP

Run No.	Pressure Plate Force (lb)	Pressure Plate Force (N)	Direction of Force (deg)	Engine rpm STBD	Engine rpm PORT	Propulsor Unit Angle (deg) STBD	Propulsor Unit Angle (deg) PORT	Propeller rpm STBD	Propeller rpm PORT	Tanker rpm	Tanker Speed (knot)	Tanker Heading (deg)
400	32,290	143,626	90	2260	1883	0	0	382	319	0	0	351
410	32,270	143,537	90	2254	1878	5	5	381	318	10	2	351
420	30,000	133,440	90	2248	1873	10	8	380	317	20	4	355
430	29,320	130,415	55	2194	1828	5	2	371	309	30	6	355

TABLE 5 - EFFECTIVENESS OF A TRAILING TUGBOAT WHEN PULLING WITH ASTERN THRUST

Run No.	Hawser Line Pull (lb)	Hawser Line Pull (N)	Direction of Pull (deg)	Engine RPM Port	Engine RPM STBD	Propeller RPM Port	Propeller RPM STBD	Propulsor Unit Angle (deg) Port	Propulsor Unit Angle (deg) STBD	Tanker RPM	Tanker Speed (knot)	Tanker Heading (deg)
500	29,880	132,906	180	2010	2010	340	340	180	180	0	0	351
501	28,590	127,168	180	2010	2010	340	340	180	180	10	2	351
502	27,640	122,943	180	2010	2010	340	340	180	180	20	4	351
503	27,280	121,341	180	2010	2010	340	340	180	180	25	5	344
504	27,550	122,542	180	2010	2010	340	340	180	180	30	6	348
510	29,900	132,995	180	2010	2010	340	340	180	180	20	4	350
520	27,660	123,032	180	1950	1950	330	330	180	180	30	6	355
530	26,760	119,028	180	1900	1900	321	321	195	165	30	6	000
540	21,680	96,433	180	1700	1700	288	288	210	150	30	6	002

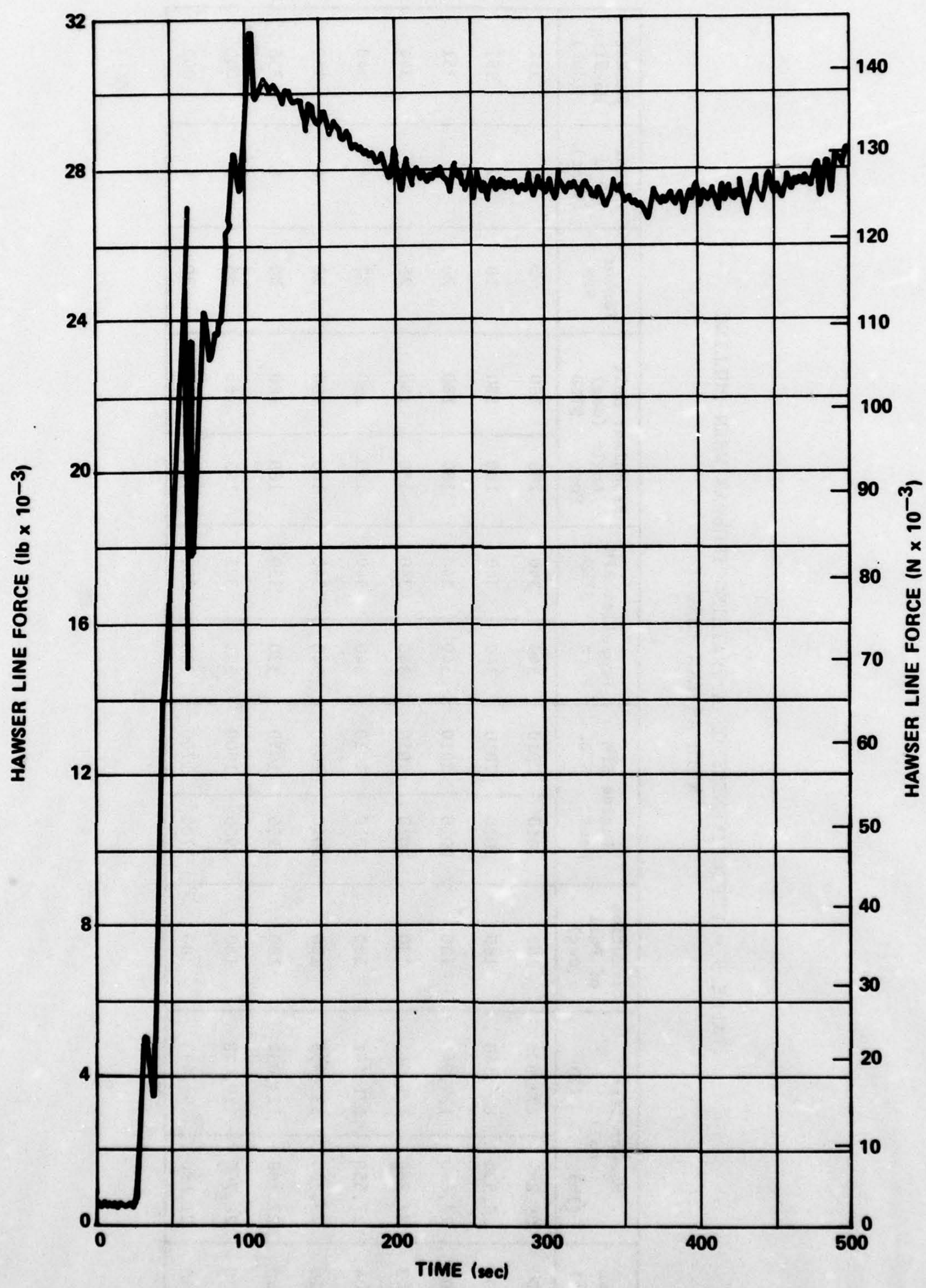

Figure 17 - Computer Plot of Run 500 Showing Recorded Line Pull versus Time

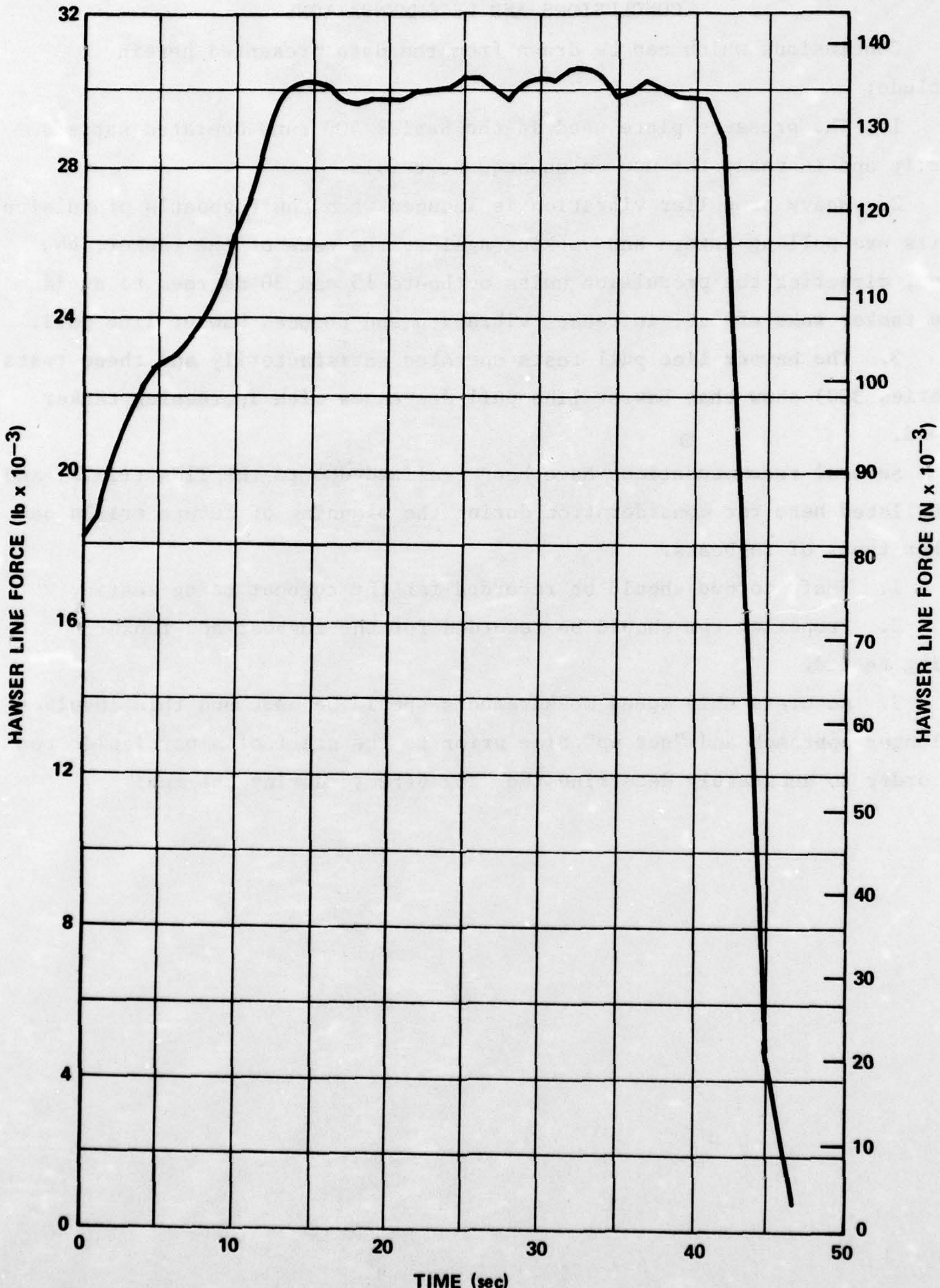

Figure 18 - Computer Plot of Run 510 Showing Recorded Line Pull versus Time

CONCLUSIONS AND RECOMMENDATIONS

Conclusions which can be drawn from the data presented herein include:

1. The pressure plate used in the Series 400 runs operated satisfactorily and is ready for use on subsequent trials.

2. Heavy propeller vibration is induced when the tugboat's propulsion units are pulling astern and working against the wake of the tanker; however, directing the propulsion units outboard 15 and 30 degrees to avoid the tanker wake effect, increases vibration and reduces hawser line pull.

3. The hawser line pull tests operated satisfactorily and these tests (Series 300) show that hawser line pull decreases with increasing tanker speed.

Several recommendations have been realized due to the TINA trials, and are listed here for consideration during the planning of future trials on other types of tugboats.

1. Shaft torque should be recorded for the tugboat being tested.

2. Propeller rpm should be recorded for the tugboat and tanker being tested.

3. Accurate ship speed measurements should be made and this involves a longer approach and "set up" time prior to the start of a particular run in order to accurately determine the "tug effect" during the run.

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